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Information Visualization Research Publications during 1990-2018: A Scientometric Analysis

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Information visualization research publications during 1990-2018: A scientometric analysis

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Abstract: *To understand the history and research status of information visualization, information visualization research citation data has been collected from the Scopus expanded during the period from 1990 to 2018. Results indicated that the research of information visualization has increased during the studied 29-year period. The country with the highest research output was the United States with 1996 publications, while the institution with the highest research output was the CNRS Centre National de la Recherche Scientifique. The majority of research articles have been contributed from developed countries. It also revealed that developed countries have more research advantages in comparison to developing countries. The top three outputs journals were Nucleic Acids Research, BMC Bioinformatics and Bioinformatics.*

Keywords: *Information visualization, Data visualization, Scientometric analysis, scientific research.*

Introduction

Information visualization (or infovis) seeks to augment human cognition by leveraging human visual capabilities to make sense of abstract information (Card et al, 1999). It is a representation of data in a visual context, which helps to understand the significance of data (Chen, 2017, p.7). Information Visualization has been a method for humans to communicate knowledge about events beyond the boundary of space and time. The cave drawings are best example of information visualization used by humans in the absence of proper communicating languages. These drawings are very detailed and it helps in understanding the events happening at that time. Same is applicable in current use of visualization techniques; by using intuitive, meaningful and detailed representation, we can make the audience understand highly abstracted information or knowledge with mild efforts. It is already recognized fact that visual information is more easily understandable than information presented in linear textual form. Further, with the advent of human technological advancement new ways expression of abstract knowledge, are being invented. Virtual reality, Augmented reality, Holographic technologies are some current examples, which have high potential for abstract information visualization. It is necessary to find

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new ways to present the exponentially increasing information in the knowledge-world. As we live in a three dimensional world and it is very well perceivable by our human senses, it is an excellent idea to explore the possibilities of representing information in 3-D space, it has the capability to present even more highly abstracted knowledge with more detail. Besides these, it has also been found to be highly useful for various analytics purposes, assisting in more confident decision making (Padilla, Creem-Regehr, Hegarty, & Stefanucci, 2018). All these advantages have guided the researchers over the years to explore the domain of Information Visualization. A simple search in the Web of Science database for the term Information Visualization results in more than 21000 documents published since 1989. This work attempts to quantify and understand the past research growth and collaboration patterns by means of scientometric analysis. Scientometrics is a quantitative method which utilises various indicators to assess the growth and pattern of publication of scholarly literature, author collaborations and citations.

Objective of the study

The main objectives of the present study are as follows:

- To identify the form wise distribution of publications;
- To find out the year wise distribution of the publications;
- To find out annual and compound growth rate of publications;
- To find out the authorship pattern of the publications;
- To scrutinize the authors productivity;
- To determine the degree of collaboration among single and multiple authors;
- To explore the country wise and institutions (affiliation) wise publications;
- To find out the subject wise distribution of publications;
- To find out the most favored source titles;
- To find out the funding institutions and the highly cited publications

Methodology

Scopus is one of the largest abstract and citation databases of peer-reviewed scholarly publications. It covers the world's research output in the fields of science, technology, medicine, social sciences, and arts and humanities (https://www.elsevier.com/en-in/solutions/scopus). We first retrieved all research publications on information visualization via the Scopus database. We searched using keywords “information” AND “visualization” on 12 Sept 2019. Our search yielded 6192 records made up of several document types, including articles, review, conference paper, note, editorial, short survey, letter, erratum and data paper. The data were exported into a text-based format via the Scopus website, then imported into MS-Excel and analyzed. The output

and citations for each year, country, institution and journal were summarized; further, we analyzed high-impact articles, high-impact authors and research trends.

Results and discussion

Document type

There were 09 document types acknowledged in the 6192 records. The majority of the documents were articles, which accounted for 90.42% of the total records, demonstrating that these are the main approach for scientific communication on information visualization. Review and conference papers, taking up of 6.27% and 2.36%, respectively, were two other significant ways to publish academic achievements in this field of research.

Table 1 Form wise distribution of documents

Type	Documents	%
Article	5599	90.42
Review	388	6.27
Conference Paper	146	2.36
Note	18	0.29
Editorial	11	0.18
Short Survey	11	0.18
Letter	9	0.15
Erratum	7	0.11
Data Paper	3	0.05
Total	6192	100.00

Yearly research outputs

Table 2 shows research output each year from 1990 to 2018, according to the data we collected on 12 September 2019. It indicates a fluctuating increase from approximately 3-899 records during the last 29 years after 1990. In this period, the overall trend has been an increase of yearly output. Results revealed that the research on information visualization was consistently the focus of scholars during the past 29 years.

Table 2 Yearly research outputs

Year	TP	%	TC	ACPP	Year	TP	%	TC	ACPP
1990	3	0.05	173	57.67	2005	168	2.71	19329	115.05
1991	10	0.16	678	67.80	2006	165	2.66	8939	54.18
1992	12	0.19	169	14.08	2007	217	3.50	9781	45.07
1993	7	0.11	120	17.14	2008	237	3.83	11564	48.79
1994	12	0.19	457	38.08	2009	262	4.23	21745	83.00
1995	23	0.37	5128	222.96	2010	253	4.09	16201	64.04
1996	23	0.37	582	25.30	2011	313	5.05	14853	47.45
1997	25	0.40	824	32.96	2012	344	5.56	15771	45.85
1998	18	0.29	1776	98.67	2013	400	6.46	16224	40.56
1999	29	0.47	3135	108.10	2014	513	8.28	15182	29.59
2000	50	0.81	8363	167.26	2015	609	9.84	13486	22.14

2001	35	0.57	2313	66.09	2016	597	9.64	9292	15.56
2002	63	1.02	4262	67.65	2017	698	11.27	6449	9.24
2003	85	1.37	11773	138.51	2018	899	14.52	2603	2.90
2004	122	1.97	12331	101.07	Total	6192	100.00	233503	37.71

TP=Total paper, %= percentage out of Total, TC=Total Citation, ACPP=Average citation per paper

Annual and cumulative growth rate of the publications

Table 3 provides the AGR of the number of documents for period 1990-2018.

$$AGR = \frac{end\ value - first\ value}{first\ value} \times 100$$

Table 3 shows that the annual growth rate of the total publication calculated year wise. Fluctuation is seen in throughout the study period. Here, the AGR has been determined as per the formula given above. In our study, the AGR for publications has decreasing trends from 233.33 in 1991 to -41.67 in 1993. However, the AGR has increased to 71.43 in 1994 to 91.67 in 1995. Since then, there is fluctuation in year after year as presented in Table 3.

Table 3 also provides the CAGR of the number of documents for the period 1990-2018. The equation used to calculate CAGR is given below:

$$\text{CAGR= (ending value/beginning value)}^{(1/\#\ \text{of years})}{}_{-1}$$

The compound annual growth rates of the publications are gradually decreased from 0.63 in 1991 to 0.09 in 1993 as seen in table 3. However, the CAGR has increased to 0.11 in 1994 to 0.15 in 1995. This indicates that though the yearly output is fluctuating year after year as seen in table 3.

Table 3 Annual and cumulative growth rate

Year	N_d	AGR	N_c	CAGR	Year	N_d	AGR	N_c	CAGR
1990	3	0	3	0	2005	168	37.70	685	0.10
1991	10	233.33	13	0.63	2006	165	-1.79	850	0.07
1992	12	20.00	25	0.24	2007	217	31.52	1067	0.08
1993	7	-41.67	32	0.09	2008	237	9.22	1304	0.07
1994	12	71.43	44	0.11	2009	262	10.55	1566	0.06
1995	23	91.67	67	0.15	2010	253	-3.44	1819	0.05
1996	23	0.00	90	0.10	2011	313	23.72	2132	0.05
1997	25	8.70	115	0.09	2012	344	9.90	2476	0.05
1998	18	-28.00	133	0.05	2013	400	16.28	2876	0.05
1999	29	61.11	162	0.07	2014	513	28.25	3389	0.06
2000	50	72.41	212	0.09	2015	609	18.71	3998	0.06
2001	35	-30.00	247	0.05	2016	597	-1.97	4595	0.05
2002	63	80.00	310	0.08	2017	698	16.92	5293	0.05
2003	85	34.92	395	0.08	2018	899	28.80	6192	0.05
2004	122	43.53	517	0.09	Total	6192	841.8	-	2.77

N_d= Number of documents in the year, N_c= Cumulative number of documents till the year.

Authorship pattern

Table 4 represents that the maximum number of research articles were published by multiple authors 5832 (94.19%) and 360(5.81%) were published by single authors. We observed from the study that the majority of papers were published by multi-authors.

Table 4 Authorship pattern

Year	Authors		Year	Authors	
	Single	Multiple		Single	Multiple
1990	0	3	2005	10	158
1991	1	9	2006	12	153
1992	3	9	2007	18	199
1993	0	7	2008	17	220
1994	1	11	2009	16	246
1995	5	18	2010	15	238
1996	1	22	2011	20	293
1997	1	24	2012	20	324
1998	2	16	2013	18	382
1999	2	27	2014	24	489
2000	4	46	2015	36	573
2001	2	33	2016	36	561
2002	6	57	2017	28	670
2003	6	79	2018	46	853
2004	10	112	Total	360	5832

Most prolific authors

Table 5 shows top ten prolific authors with their contributions. It is observed that Herrmjakob, H has contributed 14 papers scored first rank followed by Karp, P. D. 12 papers scored second rank and Chaussabel, D. 10 papers. On the other hand, Birney, E., Evelo, C. T., Kohlbacher, O., Markl, M., Pico, A. R., have 9 papers each whereas, Boughorbel, S. and Cherry, J. M. contributed 8 papers each.

Table 5 Ten top most prolific authors

Sl. No.	Author	Documents
1	Hermjakob, H.	14
2	Karp, P. D.	12
3	Chaussabel, D.	10
4	Birney, E.	9
5	Evelo, C.T.	9
6	Kohlbacher, O.	9
7	Markl, M.	9
8	Pico, A. R.	9
9	Boughorbel, S.	8
10	Cherry, J. M.	8

Degree of collaboration

The DC is defined as the ratio of the number of collaborative research papers to the total number of research papers in the discipline during a certain period of time. The formula suggested by Subramaniam (1983) is used. It is expressed as:

$$\mathrm{DC} = \frac{Nm}{Nm + Ns}$$

Where, DC is Degree of Collaboration in a discipline,

Nm - Is the number of multi-authored research papers in the discipline published during the year,

Ns - Is the number of single-authored papers in the discipline published during the same year. Using this formula, the DC is determined for each year. Table 6 shows year wise variation of DC. It can be observed that degree of collaboration has been above 90 percent.

Table 6 Degree of collaboration

Year	N_s	N_m	N_s+N_m	DC	Year	N_s	N_m	N_s+N_m	DC
1990	0	3	3	1.00	2005	10	158	168	0.94
1991	1	9	10	0.90	2006	12	153	165	0.93
1992	3	9	12	0.75	2007	18	199	217	0.92
1993	0	7	7	1.00	2008	17	220	237	0.93
1994	1	11	12	0.92	2009	16	246	262	0.94
1995	5	18	23	0.78	2010	15	238	253	0.94
1996	1	22	23	0.96	2011	20	293	313	0.94
1997	1	24	25	0.96	2012	20	324	344	0.94
1998	2	16	18	0.89	2013	18	382	400	0.96
1999	2	27	29	0.93	2014	24	489	513	0.95
2000	4	46	50	0.92	2015	36	573	609	0.94
2001	2	33	35	0.94	2016	36	561	597	0.94
2002	6	57	63	0.90	2017	28	670	698	0.96
2003	6	79	85	0.93	2018	46	853	899	0.95
2004	10	112	122	0.92	Total	360	5832	6192	0.94

Nm= Number of multiple authors, Ns= Number of single authors, DC= Degree of Collaboration.

Countries-wise distribution of research output

Table 7 shows the analysis of the country-wise distribution of research output can help us to identify the capacity of a country and discover the capacity differences among different countries. 115 countries have been contributed in this domain, but it shows that more than 50 percent documents came from developed countries. As Table 7 shows, that among the top ten countries were United States, Germany, United Kingdom, China, Japan, Canada, Netherland, France, Spain and Australia; their published papers occupied 93.15% of the total output. These countries, except China, all are developed countries.

Table 7 Top ten most productive countries

Sl. No.	Country	Documents
1	United States	1996
2	Germany	742
3	United Kingdom	694
4	China	616
5	Japan	460
6	Canada	283
7	Netherlands	274
8	France	262
9	Spain	234
10	Australia	207

Institution-wise distribution of research output

Institution-wise distribution of research output can help us understand the research capacity and activities of institutions around the world. It also can help us to identify leading institutions in information visualization research. From Table 8, it can be seen that the highest institutional research output was from the CNRS Centre National de la Recherche Scientifique, from which we found 90 records. Results showed that the USA and UK allocated a large number of resources to information visualization research, especially to government and government-supported scientific organizations. The reason may be that the field of information visualization is one of the fundamental scientific research and primarily non-profit, therefore requiring funds and support from the government should be given.

Table 8 Top twenty most prolific Institutions

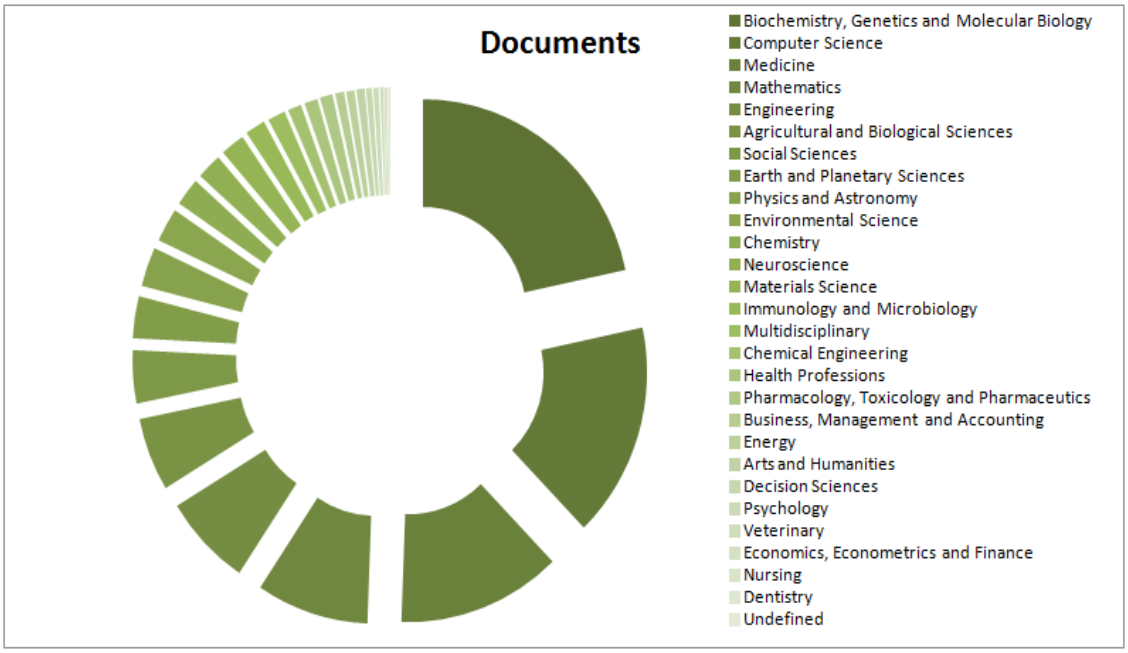
Sl. No.	Institution (Affiliation)	Documents	Country
1	CNRS Centre National de la Recherche Scientifique	90	France
2	European Bioinformatics Institute	89	UK
3	Chinese Academy of Sciences	87	China
4	Harvard Medical School	71	USA
5	University of California, San Diego	70	USA
6	National Institutes of Health, Bethesda	68	USA
7	Inserm	55	France
8	Ministry of Education China	54	China
9	University of Toronto	54	Canada
10	Imperial College London	53	UK
11	European Molecular Biology Laboratory	49	Germany
12	University of Washington, Seattle	49	USA
13	University of Tokyo	46	Japan
14	University of Oxford	46	UK
15	University of Cambridge	46	UK
16	Stanford University	44	USA
17	University of California, Davis	44	USA
18	Massachusetts Institute of Technology	44	USA
19	University of California, San Francisco	44	USA
20	University of Michigan, Ann Arbor	44	USA

Subject-wise distribution of research output

Tables 9 examine the subject wise distribution of publications which were produced during the stipulated period. This study identifies the authors' interest and involvement of subjects in terms of producing the publication in their respective specialization. It shows that most of the subjects are overlapped with each other. The findings of the study reveal that the highest number 2604 (42.05%) of scientific scholarly publications were published in the subject of Biochemistry, Genetics and Molecular Biology study due to the rapid growth of development in the area that the majority of authors are very much interested to do their research work and followed by 31.31% of papers were from computer science and 24.85% of papers were from medicine.

Table 9 Subject wise distribution of documents

Sl. No.	Subject area	Documents	%
1	Biochemistry, Genetics and Molecular Biology	2604	42.05
2	Computer Science	1939	31.31
3	Medicine	1539	24.85
4	Mathematics	1055	17.04
5	Engineering	836	13.50
6	Agricultural and Biological Sciences	662	10.69
7	Social Sciences	478	7.72
8	Earth and Planetary Sciences	379	6.12
9	Physics and Astronomy	355	5.73
10	Environmental Science	308	4.97
11	Chemistry	253	4.09
12	Neuroscience	237	3.83
13	Materials Science	228	3.68
14	Immunology and Microbiology	190	3.07
15	Multidisciplinary	167	2.70
16	Chemical Engineering	128	2.07
17	Health Professions	124	2.00
18	Pharmacology, Toxicology and Pharmaceutics	119	1.92
19	Business, Management and Accounting	83	1.34
20	Energy	77	1.24



Journal-wise distribution of research output

There were more than 170 journals that published 6192 articles in the area of information visualization. Table 10 shows the top 20 records journals, which had 2214 articles, thus comprising 35.76% of all 6192 articles. As Table 5 shows, the journal with the most outputs was Nucleic Acids Research, with 446 records, accounting for 7.2% of the total number of records. The following four journals were Nucleic Acids Research, BMC Bioinformatics, Bioinformatics and Plos One, which published 446, 383, 378 and 272 articles, occupying 7.2%, 6.2%, 6.1% and 4.4% of the total records, respectively. From the scope of top 20 records journals, information visualization research mostly concentrated on medical science, computer science and engineering. The researchers from these disciplines paid much attention to the field of information visualization.

Table 10 Top twenty most prolific Journals

Sl. No.	Source	documents
1	Nucleic Acids Research	446
2	BMC Bioinformatics	383
3	Bioinformatics	378
4	Plos One	272
5	IEEE Access	80
6	BMC Genomics	70
7	Scientific Reports	64
8	Journal Of Biomedical Informatics	58
9	ISPRS International Journal Of Geo Information	55
10	IEICE Transactions On Information And Systems	53
11	Sensors Switzerland	49
12	F1000research	39
13	Journal of the American Medical Informatics Association	39
14	Database	36

15	Proceedings of The National Academy of Sciences of The United States of America	36
16	Journal of Medical Internet Research	35
17	International Journal of Health Geographics	32
18	Remote Sensing	31
19	Frontiers In Neuroinformatics	30
20	Plos Computational Biology	28

Funding Institutes of research output

Table 11 shows the rank of top 20 research funding agencies / institutions. The National Institutes of Health, National Natural Science Foundation of China and National Science Foundation are the top contributing research project funding agencies which result 692(26.26 %) research publication during the year 1990-2018. Total 2635(42.55%) research papers were published through the funded research projects.

Table 11 Top twenty funding Institutes

Sl. No.	Funding Institute	Documents
1	National Institutes of Health	302
2	National Natural Science Foundation of China	222
3	National Science Foundation	168
4	Deutsche Forschungsgemeinschaft	69
5	Engineering and Physical Sciences Research Council	64
6	European Commission	62
7	Wellcome Trust	54
8	Biotechnology and Biological Sciences Research Council	52
9	Japan Society for the Promotion of Science	51
10	U.S. Department of Energy	48
11	European Research Council	44
12	Natural Sciences and Engineering Research Council of Canada	39
13	Bundesministerium für Bildung und Forschung	38
14	National Research Foundation of Korea	38
15	National Human Genome Research Institute	37
16	National Cancer Institute	35
17	Canadian Institutes of Health Research	32
18	Foundation for the National Institutes of Health	31
19	U.S. National Library of Medicine	30
20	Ministry of Education, Culture, Sports, Science and Technology	29

Top ten highly cited articles

The highly cited articles got 5998 citations, about 2.57% of all citations. However, it was noticed that none of the prolific authors is a highly cited author. Further analysis of the highly cited papers indicates that these papers came from developed countries, mainly from the USA, Spain, Germany, England and so on. Most of the highly cited papers are in the area of genetics, medicine and computer science, which are cited more frequently as compared to other areas.

Table 12 Top ten highly cited articles

Authors	Cited by	Title	Year	Country
Conesa A, Götz S, García-Gómez JM, Terol J, Talón M, Robles M.	5998	Blast2GO: A universal tool for annotation, visualization and analysis in functional genomics research	2005	Spain
Rozas J, Sánchez-DelBarrio JC, Messeguer X, Rozas R	4811	DnaSP, DNA polymorphism analyses by the coalescent and other methods	2003	Spain
Ludwig, W., Strunk, O., Westram, R., Richter, L., Meier, H., Yadhukumar, A., Buchner, A., Lai, T., Steppi, S., Jacob, G., Förster,, W., Brettske, I., Gerber, S., Ginhart, A.W., Gross, O., Grumann, S., Hermann, S., Jost, R.,König, A., Liss, T., Lüßman, R., May, M., Nonhoff, B., Reichel, B., Strehlow, R., Stamatakis, A., Stuckmann, N., Vilbig, A., Lenke, M., Ludwig, T., Bode, A., Schleifer, K.-H.	4545	ARB: A software environment for sequence data	2004	Germany
Anselin, L.	4102	Local Indicators of Spatial Association—LISA	1995	USA
Westrip, S.P.	3754	PublCIF: Software for editing, validating and formatting crystallographic information files	2010	England
Krzywinski, M., Schein, J., Birol, I., Connors, J., Gascoyne, R., Horsman, D., Jones, S.J., Marra, M.A.	3497	Circos: An information aesthetic for comparative genomics	2009	Canada
Tice, R.R., Agurell, E., Anderson, D., Burlinson, B., Hartmann, A., Kobayashi, H., Miyamae, Y., Rojas, E., Ryu, J.-C., Sasaki, Y.F.	3382	Single cell gel/comet assay: Guidelines for in vitro and in vivo genetic toxicology testing	2000	USA
Cole, J.R., Wang, Q., Cardenas, E., Fish, J., Chai, B., Farris, R.J., Kulam-Syed-Mohideen, A.S., McGarrell, D.M., Marsh, T., Garrity, G.M., Tiedje, J.M.	3122	The Ribosomal Database Project: Improved alignments and new tools for rRNA analysis	2009	USA
Thorvaldsdóttir H, Robinson J T, Mesirov J P.	2624	Integrative Genomics Viewer (IGV): High-performance genomics data visualization and exploration	2013	USA
Punta, M., Coggill, P.C., Eberhardt, R.Y., Mistry, J., Tate, J., Boursnell, C., Pang, N., Forslund, K., Ceric, G., Clements, J., Heger, A., Holm, L., Sonnhammer, E.L.L., Eddy, S.R., Bateman, A., Finn, R.D.	2458	The Pfam protein families database	2012	UK

Findings

The major findings of this study are as follows:

- The highest number 14.52% of papers were published in 2018 and the lowest number 0.25% of research articles published in the year 1990.
- The result shows that majority of the documents were articles (90.42%) of the total records, it indicates that articles are the main approach for scientific communication on information visualization.
- It indicates a fluctuating increase from approximately 3-899 records during the last 29 years after 1990.
- It was observed from the study that the majority of papers were published by multi-authors 5832(94.19%).
- It was observed that Herrmjakob, H has contributed 14 papers scored first rank in most prolific authors' group.
- It was observed that degree of collaboration has been above 90 percent.
- It revealed that the top ten most productive countries, except China, all are developed countries.
- The findings of the study reveal that the highest number 2604 (42.05%) of scientific scholarly publications were published in the subject of Biochemistry, Genetics and Molecular Biology study due to the rapid growth of development in the area.
- The finding of the study shows that total 2635(42.55%) research papers were published through the project funded research.
- It was also revealed that most of the highly cited papers are in the area of genetics, medicine and computer science, which are cited more frequently as compared to other areas.
- The maximum number of citations were 21745 (9.31%) in the year 2009 whereas, the minimum number of citations were 120 (0.05%) in the year 1993.
- The highest number 2604 (42.05%) of scientific scholarly publications were published in the subject of Biochemistry, Genetics and Molecular Biology, followed by 31.31% of papers were from Computer Science, 8.46% of papers were from Medicine.

Conclusion

As we all know that information visualization plays an important role in demonstrating raw data into a visual and meaningful way so that one can better understand it. Overall, the research trend of information visualization has increased from 2004 to 2018, with its research outputs accomplished approximately from 122 to 899 records. These trends implied that information visualization research as an important research area for addressing information and visualization issues obtained a reasonably stable intellectual attention. Among the top 20 highly productive countries, United States with (1996 publications) has scored top rank. The majority of the research papers were published from Biochemistry, Genetics and Molecular Biology subjects. Maximum research papers were published in the discipline-specific journals on information visualization, such as Nucleic Acids Research, BMC Bioinformatics and Bioinformatics.

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